Restep Boost Converter Design Calculations

www.restep.eco

Chris Arntzen 1/19/18, edited 12/19/20

These design calculations and the nomenclature follow the TI LM5022-Q1 Detailed Design Procedure. Items with orange background are actual selected components and values.

Boost Converter Calculations: 48V 120W using LM5022-Q1 Controller

$V_{in\_min} := 10.5$ $V_{in\_max} := 25$ $I_{out} := 2.5$ $\eta := 0.9$ $V_d := 0.5$

Output Voltage Setting

$V_{fb\_min} := 1.225$ $V_{fb\_max} := 1.275$ $V_{div\_ratio} := \frac{1.25}{48} = 0.026$

$tol_R := 0.001$ $TCR := 25$ $T_{range} := 60$

$R_{FB1} := 1.3 \cdot 10^3$

$$R_{FB1\_min} := R_{FB1} \cdot (1 - tol_R) - (R_{FB1} \cdot TCR \cdot 10^{-6} \cdot T_{range}) = 1.297 \cdot 10^3$$

$$R_{FB1\_max} := R_{FB1} \cdot (1 + tol_R) + (R_{FB1} \cdot TCR \cdot 10^{-6} \cdot T_{range}) = 1.303 \cdot 10^3$$

$R_{FB2} := 48.7 \cdot 10^3$

$$R_{FB2\_min} := R_{FB2} \cdot (1 - tol_R) - (R_{FB2} \cdot TCR \cdot 10^{-6} \cdot T_{range}) = 4.858 \cdot 10^4$$

$$R_{FB2\_max} := R_{FB2} \cdot (1 + tol_R) + (R_{FB2} \cdot TCR \cdot 10^{-6} \cdot T_{range}) = 4.882 \cdot 10^4$$

$$V_{out\_min} := V_{fb\_min} \cdot \left(\frac{R_{FB1\_max} + R_{FB2\_min}}{R_{FB1\_max}} \right) = 46.887$$

$$V_{out\_max} := V_{fb\_max} \cdot \left(\frac{R_{FB1\_min} + R_{FB2\_max}}{R_{FB1\_min}} \right) = 49.278$$

Switching Frequency

$f_{s\_nom} := 400 \cdot 10^3$ $\quad tol_{fosc} := .1375$ $\quad R_{T\_calc} := \frac{\left(1 - 8 \cdot 10^{-8} \cdot f_{s\_nom}\right)}{f_{s\_nom} \cdot 5.77 \cdot 10^{-11}} = 4.194 \cdot 10^4$

$R_T := 42.2 \cdot 10^3$

$$R_{T\_min} := R_T \cdot \left(1 - tol_R\right) - \left(R_T \cdot TCR \cdot 10^{-6} \cdot T_{range}\right) = 4.209 \cdot 10^4$$

$$R_{T\_max} := R_T \cdot \left(1 + tol_R\right) + \left(R_T \cdot TCR \cdot 10^{-6} \cdot T_{range}\right) = 4.231 \cdot 10^4$$

$$f_{s\_min} := \left(\frac{1}{8 \cdot 10^{-8} + 5.77 \cdot 10^{-11} \cdot R_{T\_max}}\right) \left(1 - tol_{fosc}\right) = 3.421 \cdot 10^5$$

$$f_{s\_max} := \left(\frac{1}{8 \cdot 10^{-8} + 5.77 \cdot 10^{-11} \cdot R_{T\_min}}\right) \left(1 + tol_{fosc}\right) = 4.534 \cdot 10^5$$

Power and Duty Cycle

$P_{out\_min} := V_{out\_min} \cdot I_{out} = 117.216$ $\quad P_{out\_max} := V_{out\_max} \cdot I_{out} = 123.195$

$P_{in\_min} := \frac{P_{out\_min}}{\eta} = 130.24$ $\quad P_{in\_max} := \frac{P_{out\_max}}{\eta} = 136.883$

$I_{in\_min} := \frac{P_{in\_min}}{V_{in\_max}} = 5.21$ $\quad I_{in\_max} := \frac{P_{in\_max}}{V_{in\_min}} = 13.036$

$D_{min} := \frac{\left(V_{out\_min} - V_{in\_max} + V_d\right)}{V_{out\_min} + V_d} = 0.472$ $\quad D_{max} := \frac{\left(V_{out\_max} - V_{in\_min} + V_d\right)}{V_{out\_max} + V_d} = 0.789$

Inductor and Currents

Coilcraft SER2918H-153KL 15uH 10% DCR=2.86mΩ Isat=21.9A Irms=28A

$L_{nom} := 15 \cdot 10^{-6}$ $\quad tol_L := 0.1$ $\quad L_{min} := L_{nom} \cdot (1 - tol_L) = 1.35 \cdot 10^{-5}$

$I_{sat\_rat} := 21.9$ $\quad I_{rms\_rat} := 28$ $\quad L_{max} := L_{nom} \cdot (1 + tol_L) = 1.65 \cdot 10^{-5}$

$$\Delta I_{L\_min} := \left(\frac{V_{in\_min}}{L_{max}}\right)\left(\frac{D_{max}}{f_{s\_max}}\right) = 1.107 \qquad \Delta I_{L\_max} := \left(\frac{V_{in\_max}}{L_{min}}\right)\left(\frac{D_{min}}{f_{s\_min}}\right) = 2.557$$

$$I_{Lrms\_min} := \sqrt{I_{in\_min}^{\ 2} + \left(\frac{\Delta I_{L\_max}}{12}\right)^2} = 5.214 \qquad I_{Lrms\_max} := \sqrt{I_{in\_max}^{\ 2} + \left(\frac{\Delta I_{L\_min}}{12}\right)^2} = 13.037$$

$$I_{Lpk\_min} := I_{in\_min} + \frac{\Delta I_{L\_max}}{2} = 6.488 \qquad I_{Lpk\_max} := I_{in\_max} + \frac{\Delta I_{L\_min}}{2} = 13.59$$

$$I_{Lpk\_op} := \frac{I_{Lpk\_max}}{I_{sat\_rat}} = 0.621 \qquad I_{Lrms\_op} := \frac{I_{Lrms\_max}}{I_{rms\_rat}} = 0.466$$

$$K_{min} := \frac{\Delta I_{L\_min}}{I_{Lrms\_max}} = 0.085 \qquad K_{max} := \frac{\Delta I_{L\_max}}{I_{Lrms\_min}} = 0.49$$

Output Capacitor and Output Voltage Ripple

Kemet C1812C335K1RAC7800 3.3uF X7R 1812 100V 10% 20% DC Bias Derating

$tol_C := 0.1$ $\quad DC_{bias} := 0.2$ $\quad Qty := 3$ $\quad C_{nom} := 3.3 \cdot 10^{-6}$

$$C_{out\_min} := Qty \cdot C_{nom} \cdot (1 - tol_C) \cdot (1 - DC_{bias}) = 7.128 \cdot 10^{-6}$$

$$C_{out\_max} := Qty \cdot C_{nom} \cdot (1 + tol_C) \cdot (1 - DC_{bias}) = 8.712 \cdot 10^{-6}$$

$$\Delta V_{out\_max} := \frac{D_{max} \cdot I_{out}}{f_{s\_min} \cdot C_{out\_min}} = 0.809 \qquad \Delta V_{percent} := \frac{\Delta V_{out\_max}}{V_{out\_max}} = 0.016$$

Current Sense Resistor Calculations

$V_{CL\_nom} := 0.5$ $V_{CL\_min} := 0.434$ $V_{CL\_max} := 0.55$ $I_{LIM} := 20$

$$R_{SNS\_min\_calc} := \frac{L_{min} \cdot f_{s\_min} \cdot V_{CL\_min}}{\left(V_{out\_max} - V_{in\_min}\right) \cdot 3 \cdot D_{max} + L_{min} \cdot f_{s\_min} \cdot I_{LIM}} = 0.011$$

$$R_{SNS\_max\_calc} := \frac{L_{max} \cdot f_{s\_max} \cdot V_{CL\_max}}{\left(V_{out\_min} - V_{in\_min}\right) \cdot 3 \cdot D_{max} + L_{max} \cdot f_{s\_max} \cdot I_{LIM}} = 0.017$$

VISHAY WSHM2818R0200FEA RES 0.02 OHM 1% 7W 75PPM 2818

$tol_{Rsns} := 0.01$ $TCR_{Rsns} := 75$

$R_{SNS} := 20 \cdot 10^{-3}$

$$R_{SNS\_min} := R_{SNS} \cdot \left(1 - tol_{Rsns}\right) - \left(R_{SNS} \cdot TCR_{Rsns} \cdot 10^{-6} \cdot T_{range}\right) = 0.0197$$

$$R_{SNS\_max} := R_{SNS} \cdot \left(1 + tol_{Rsns}\right) + \left(R_{SNS} \cdot TCR_{Rsns} \cdot 10^{-6} \cdot T_{range}\right) = 0.0203$$

$$I_{Rsns\_rms\_min} := \sqrt{D_{min} \cdot \left(I_{Lpk\_min}^{2} + \frac{\Delta I_{L\_max}^{2}}{3} - I_{Lpk\_min} \cdot \Delta I_{L\_max}\right)} = 3.616$$

$$I_{Rsns\_rms\_max} := \sqrt{D_{max} \cdot \left(I_{Lpk\_max}^{2} + \frac{\Delta I_{L\_min}^{2}}{3} - I_{Lpk\_max} \cdot \Delta I_{L\_min}\right)} = 11.584$$

$P_{Rsns\_min} := I_{Rsns\_rms\_min}^{2} \cdot R_{SNS\_min} = 0.258$ $P_{Rsns\_max} := I_{Rsns\_rms\_max}^{2} \cdot R_{SNS\_max} = 2.723$

Current Sense Filter

$R_{S1} := 499$ $C_{CS} := 470 \cdot 10^{-12}$

$$f_{CS} := \frac{1}{2 \cdot \pi \cdot R_{S1} \cdot C_{CS}} = 6.786 \cdot 10^{5}$$

Slope Compensation Resistor

$$R_{S2\_min\_calc} := \frac{V_{CL\_min} - I_{LIM} \cdot R_{SNS\_min}}{45 \cdot 10^{-6} \cdot D_{max}} = 1.121 \cdot 10^{3}$$

$$tol_{RS} := 0.001$$

$$R_{S2\_max\_calc} := \frac{V_{CL\_max} - I_{LIM} \cdot R_{SNS\_max}}{45 \cdot 10^{-6} \cdot D_{min}} = 6.783 \cdot 10^{3}$$

$$TCR_{RS} := 25$$

$$R_{S2} := 1.69 \cdot 10^{3}$$

$$R_{S2\_min} := R_{S2} \cdot \left(1 - tol_{RS}\right) - \left(R_{S2} \cdot TCR_{RS} \cdot 10^{-6} \cdot T_{range}\right) = 1.6858 \cdot 10^{3}$$

$$R_{S2\_max} := R_{S2} \cdot \left(1 + tol_{RS}\right) + \left(R_{S2} \cdot TCR_{RS} \cdot 10^{-6} \cdot T_{range}\right) = 1.6942 \cdot 10^{3}$$

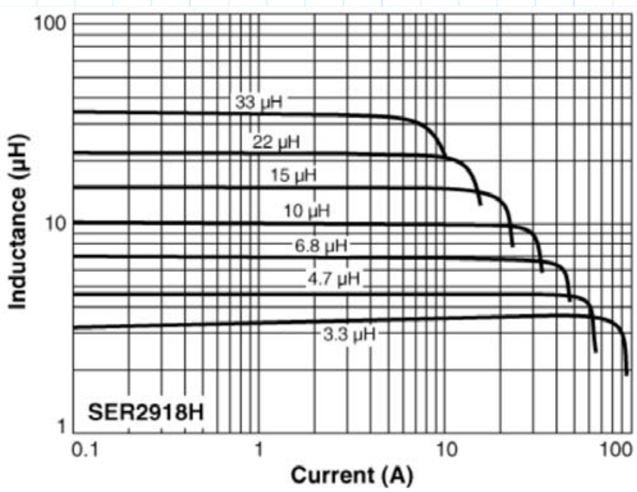
$$R_{S1\_min} := R_{S1} \cdot \left(1 - tol_{RS}\right) - \left(R_{S1} \cdot TCR_{RS} \cdot 10^{-6} \cdot T_{range}\right) = 497.753$$

$$R_{S1\_max} := R_{S1} \cdot \left(1 + tol_{RS}\right) + \left(R_{S1} \cdot TCR_{RS} \cdot 10^{-6} \cdot T_{range}\right) = 500.248$$

Current Limit Trip Point

$$I_{TRIP\_min} := \frac{V_{CL\_min} - 45 \cdot 10^{-6} \cdot D_{max} \cdot \left(R_{S2\_max} + R_{S1\_max} + 2000\right)}{R_{SNS\_max}} = 14.049$$

$$I_{TRIP\_max} := \frac{V_{CL\_max} - 45 \cdot 10^{-6} \cdot D_{min} \cdot \left(R_{S2\_min} + R_{S1\_min} + 2000\right)}{R_{SNS\_min}} = 23.392$$



Slope Compensation Comparison

$$S_{n\_min} := \frac{R_{SNS\_min} \cdot V_{in\_min}}{L_{max}} = 1.254 \cdot 10^4$$

$$S_{n\_max} := \frac{R_{SNS\_max} \cdot V_{in\_max}}{L_{min}} = 3.757 \cdot 10^4$$

$$S_{e\_min} := 45 \cdot 10^{-6} \cdot f_{s\_min} \cdot \left(R_{S1\_min} + R_{S2\_min} + 2000\right) = 6.441 \cdot 10^4$$

$$S_{e\_max} := 45 \cdot 10^{-6} \cdot f_{s\_max} \cdot \left(R_{S1\_max} + R_{S2\_max} + 2000\right) = 8.558 \cdot 10^4$$

Want slope compensation ramp ratio of 1, or at least 0.5 (Se/Sn)

$$SC_{ratio\_min} := \frac{S_{e\_min}}{S_{n\_max}} = 1.714$$

$$SC_{ratio\_max} := \frac{S_{e\_max}}{S_{n\_min}} = 6.823$$

Loss Calculations

VISHAY SQJA92EP-T1_GE3 MOSFET

$R_{DS\_ON\_max} := 0.0095 \cdot 1.3 = 0.012$ $\quad t_r := 10 \cdot 10^{-9}$ $\quad t_f := 25 \cdot 10^{-9}$ $\quad Q_g := 45 \cdot 10^{-9}$

$I_{CC} := 0.004$ $\quad I_{GC} := Q_g \cdot f_{s\_max} = 0.02$ $\quad P_{Q\_max} := V_{in\_max} \cdot \left(I_{CC} + I_{GC}\right) = 0.61$

$$P_{SW\_max} := 0.5 \cdot V_{in\_min} \cdot I_{in\_max} \cdot \left(t_r + t_f\right) \cdot f_{s\_max} = 1.086$$

$$P_{COND\_max} := D_{max} \cdot I_{in\_max}{}^2 \cdot R_{DS\_ON\_max} = 1.656$$

$$P_{FET\_max} := P_{SW\_max} + P_{COND\_max} = 2.742$$

NOTE: the FET selected above failed during testing at full load and low line, likely due to operation outside of the FET SOA. The FET below is the chosen replacement and did not fail during testing.

VISHAY SUM70060E MOSFET

$R_{DS\_ON\_max} := 0.0062 \cdot 1.3 = 0.008$ $\quad t_r := 44 \cdot 10^{-9}$ $\quad t_f := 18 \cdot 10^{-9}$ $\quad Q_g := 81 \cdot 10^{-9}$

$I_{CC} := 0.004$ $\quad I_{GC} := Q_g \cdot f_{s\_max} = 0.037$ $\quad P_{Q\_max} := V_{in\_max} \cdot \left(I_{CC} + I_{GC}\right) = 1.018$

$$P_{SW\_max} := 0.5 \cdot V_{in\_min} \cdot I_{in\_max} \cdot \left(t_r + t_f\right) \cdot f_{s\_max} = 1.924$$

$$P_{COND\_max} := D_{max} \cdot I_{in\_max}{}^2 \cdot R_{DS\_ON\_max} = 1.081$$

$$P_{FET\_max} := P_{SW\_max} + P_{COND\_max} = 3.005$$

Diodes Inc. SDT5H100P5-7 Schottky Rectifier

$P_{D\_max} := V_d \cdot I_{out} = 1.25$

Inductor losses estimated by Coilcraft online loss calculator @ 50degC, max Iin & fs

$P_{L\_max} := 0.554$ Almost all loss is due to winding DCR

$P_{LOSS\_max} := P_{L\_max} + P_{D\_max} + P_{FET\_max} + P_{Q\_max} + P_{Rsns\_max} = 8.549$

$$\eta_{est} := \frac{P_{out\_max}}{P_{out\_max} + P_{LOSS\_max}} = 0.935$$

Under Voltage Lock Out

$V_{SD\_min} := 1.22$ $V_{SD\_max} := 1.28$ $tol_{Ruv} := 0.01$ $TCR_{Ruv} := 100$

$R_{UVbot} := 1.47 \cdot 10^3$ $R_{UVtop} := 10 \cdot 10^3$

$R_{UVbot\_min} := R_{UVbot} \cdot (1 - tol_{Ruv}) - (R_{UVbot} \cdot TCR_{Ruv} \cdot 10^{-6} \cdot T_{range}) = 1.446 \cdot 10^3$

$R_{UVbot\_max} := R_{UVbot} \cdot (1 + tol_{Ruv}) + (R_{UVbot} \cdot TCR_{Ruv} \cdot 10^{-6} \cdot T_{range}) = 1.494 \cdot 10^3$

$R_{UVtop\_min} := R_{UVtop} \cdot (1 - tol_{Ruv}) - (R_{UVtop} \cdot TCR_{Ruv} \cdot 10^{-6} \cdot T_{range}) = 9.84 \cdot 10^3$

$R_{UVtop\_max} := R_{UVtop} \cdot (1 + tol_{Ruv}) + (R_{UVtop} \cdot TCR_{Ruv} \cdot 10^{-6} \cdot T_{range}) = 1.016 \cdot 10^4$

$$V_{UVLO\_min} := V_{SD\_min} \cdot \left(\frac{R_{UVbot\_max} + R_{UVtop\_min}}{R_{UVbot\_max}}\right) = 9.258$$

$$V_{UVLO\_max} := V_{SD\_max} \cdot \left(\frac{R_{UVbot\_min} + R_{UVtop\_max}}{R_{UVbot\_min}}\right) = 10.271$$

Soft Start

$I_{SS\_min} := 7 \cdot 10^{-6}$ $I_{SS\_max} := 13 \cdot 10^{-6}$ $V_{SS\_OFF\_min} := 0.344$ $V_{SS\_OFF\_max} := 0.75$

$C_{SS} := 100 \cdot 10^{-9}$

$C_{SS\_min} := C_{SS} \cdot 0.9 \cdot 0.85 = 7.65 \cdot 10^{-8}$

$C_{SS\_max} := C_{SS} \cdot 1.1 \cdot 1.15 = 1.265 \cdot 10^{-7}$

$$t_{SS\_min} := \frac{V_{SS\_OFF\_min} \cdot C_{SS\_min}}{I_{SS\_max}} = 0.002 \qquad t_{SS\_max} := \frac{V_{SS\_OFF\_max} \cdot C_{SS\_max}}{I_{SS\_min}} = 0.014$$